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An Integral 3D Geo-modeling Helps to Reveal New Exploration Trends - Case Study for the NW Black Sea Basin, Ukraine

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SUMMARY

An approach of integral geological and geophysical modeling has been applied to study the NW Black Sea basin (Odessa Gulf) and its local hydrocarbon prospects and leads. It was built an integral spatial geo-model that features peculiarities of deep structure and sedimentary cover of the region and outline distribution of reservoir rocks with enhanced characteristics. This 3D geo-density model was compiled in the result of integral interpretation of all available geo-data (geodynamic studies, seismic and gravity data, and information from deep wells) using original technology developed at STF BIPEKS Ltd.

Introduction

The problem how to supply Ukraine with hydrocarbons from own resources requires aiming of oil and gas explorers' efforts at the study of immature and frontier areas. One of such less explored, however, rather large and quite promising areas is aquatory of the Black Sea northwestern shelf (Fig. 1). Taking into account current geological knowledge on the area and balance between proven reserves and potential hydrocarbon resources it is possible to conclude that this immature province still requires an intensive regional exploration (Kitchka, 1998). To conduct effectively further exploration steps it is important to analyze and generalize all available geological and geophysical data to the date over the whole region under investigation.

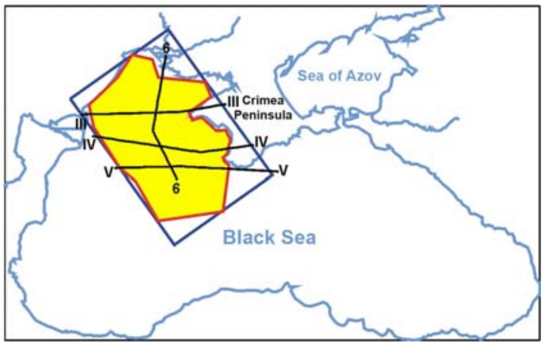

Figure 1 *Location of the area studied, in yellow.*

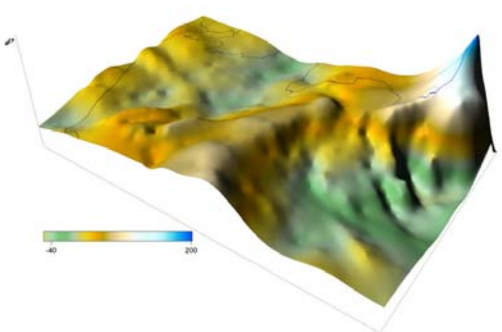

Figure 2 *Observed gravity field of the area studied.*

One of the ways for such generalization is to build an integral spatial geo-model that would feature peculiarities as of deep structure as sedimentary cover both in area and section and outline distribution of reservoir rocks with enhanced characteristics. Just such a model, namely a geo-density 3D model of the Black Sea northwestern shelf, was build in the result of integral interpretation of all available geo-data (geodynamic studies, seismic and gravity data (Fig. 2), and information from deep wells) using the technology developed at STF BIPEKS Ltd (Petrovskyy, 2005). Main stages of that technology are as follows:

- Compilation of a priori 3D geo-density model of the deep structure based on available geological and geophysical data.
- Prediction of heterogeneous macro-distribution of geo-density properties by solution of the spatial inverse linear problem of gravimetry taking into account geologically-grounded boundary conditions restricting variation of geo-density parameters and known geotectonic structure and geodynamic evolution of the area.
- Prediction of medium-scale distribution of geo-density properties taking into account of a priori dataset on the structure of a sought model, which is given in the form of a criterion information and maximum compensation of deviation between an input and computed gravity fields.
- Visualization and attribute analysis of geo-density parameters behavior within deep basement and sedimentary cover in the form of horizontal slices along axis OZ and vertical section along axes OX and OY, vertical sections along seismic, geological and synthetic profiles, cuts upon bedding planes (as along top as bottom of the bed), along an interpolated surface between the top and bottom of a selected layer.
- Geological interpretation of resulted geo-density model along with recognition of new regional elements in the basement rocks and local areas with enhanced reservoir

properties in the sedimentary cover including evaluation of their prospectivity while comparing the abovementioned with known settings of oil and gas manifestations.

As an input geological and geophysical data it was taken the following information: anomalous gravity field (in Bouguer reduction), structural maps upon seismic horizons in the sedimentary cover of 1:200000 scale (at K_1 – Lower Cretaceous bottom; $K_1{}^{al}{}_2$ – at the top of Mid-Albian; $K_2{}^{C}{}_2$ – at the bottom of Upper Cenomanian; $K_2{}^{cn\text{-}t}$ – at the Coniacian-Turonian top; $K_2{}^{st}{}_2$ – at the bottom of Upper Santonian, $K_2{}^{m(k)}$ – at the top of Upper Cretaceous carbonates; $\text{₽}^1{}_1$ – at the top of Lower Paleocene; $\text{₽}^2{}_2$ – at the top of Mid Eocene carbonates; $\text{₽}_3{}^{mk}$ – at the bottom of Maykop Series; $N_1{}^{mk}$ – at the Maykop top), bathymetric data, maps of mean seismic velocity compiled for different depth levels (-5000, -15000, and -25000 m), the map of Moho interface, and summary petrophysical characteristics of the South of Ukraine sedimentary cover.

Issuing from integrity and accuracy of available geo-data it was selected following geometric parameters of deep integral geo-model of the Black Sea northwestern shelf. The dimensions of it is 250 x 372 km laterally and 70 km vertically. As an elementary cell it was chosen a spatial parallelepiped of 2000x2000 m in length/width and 50 m of height. In total the whole model was built by 32.55 million of such elementary bodies.

A priori spatial geo-density model of the Black Sea northwestern shelf

Considering the importance of further adequate interpretation on the initial model the process of its synthesis was composed by following steps:

- Setting of parameters for the sedimentary cover that is taken upon results of seismo-structural interpretations and petrophysical parameters of sedimentary rocks with correction on their depth occurrence.
- Setting of the parameters for pre-Cretaceous rocks that is made on the basis of scaling of geo-velocity data using Gardner formula.
- Setting parameters for the upper mantle that is based on structural plots of Moho boundary surface upon deep seismic sounding data. Below it was taken density value of 3.2 g/cm^3.

For each stratigraphic level it was determined geologically-derided range of density variation, and taking into account lithological characteristics and data on porosity of proper sedimentary rocks it was formulated a criterion of optimality to classify sediments depending on their reservoir properties. Quality verification for the initial geo-density model has shown its partial discrepancy comparing with observed anomalous gravity field (standard deviation is 96 mGal). Taking into consideration a complicated tectonic structure of the area studied and presence of different crustal types, dependence of gravity field on influence of masses that occur beneath Moho it was adjusted spatial occurrence of that boundary using solution of structural inverse problem of gravity surveying. In the result standard deviation is attain 19 mGal that confirms a principle correspondence of a priori model to observed gravity field.

An integral interpretation of geo-data

After the adequacy check for complied a priori geo-density model it was conducted a final matching of computed and observed gravity fields on the basis of solution of spatial linear inverse problem for 23.25 thousand places of the field (equations) and 32.55 million of cells (unknown).

Thus, it the result of inverse problem solution it was obtained a spatial geo-density model consisted with set of all available geodata on the area in the northwestern part of Black Sea basin and gravity field (at standard deviation of 1.339 mGal). In addition of the built spatial model - it was recognized linear elements – gravity field lineaments – that were interpreted as lines related to tectonic faults while analyzing behavior of uncompensated gravity field values – deviation.

To provide detail spatial identification of basic elements of geological structure and anomalous zones as well it was made the system of sections across 3D geo-density model of the Black sea northwestern shelf horizontal and vertical (Figs. 3 and 4) ones (with double job step to define the grid of elementary cells of inhomogeneous geo-density model) and ones upon bedding plane at the top or bottom of a horizon (conformal cuts). All images employ a conventional color legend to feature density values.

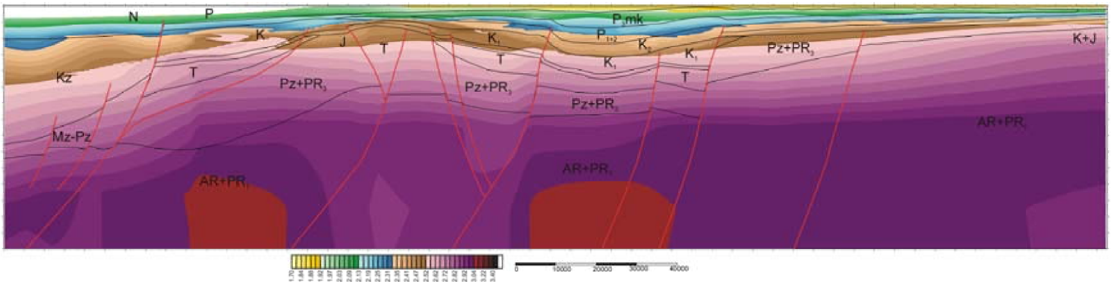

Figure 3 *N-S section 6-6 across 3D geo-density model of the region (see Fig. 1).*

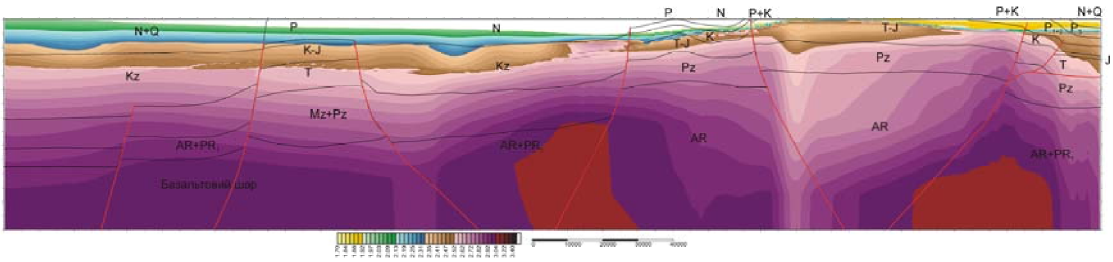

Figure 4 *W-E section V-V across 3D geo-density model of the region (see Fig. 1).*

Geological results of the study

The first element of the analysis is to attain a geological adequacy to the compiled model and gives a correspondence of basic geotectonic elements to the regional peculiarities of density distribution. Among Paleozoic tectonic elements delineated by the analysis it is worth to mention the Danube-Terek suture that in the gravity field is expressed as zone of lower density values in the “basaltic” layer and a gradient zone in the “granite” layer. The Danube-Terek suture is a boundary between two major geotectonic units – Laurussia passive margin (to the north) and active margin of Scythian Platform (south of the suture) that are also manifested in peculiarities of geo-density behavior. Besides, the model distinctly features the pre-Scythian foredeep, Scythian active margin, and Mesozoic riftogenous troughs. Mesozoic tectonic elements of the Meso-Tethys closure are the Peri-Black Sea Depression and Black Sea basin itself. An analysis of geo-density spatial behavior near the basement top (Fig. 5) allows recognition of large domains of decreased density that related to most uplifted parts of pre-Cretaceous bedrock within the Kalamit-Central Crimea swell.

The obtained principle correlation between peculiarities of geo-density distribution and modern geodynamical knowledge on the region gave a possibility to analyze distribution of sedimentary rocks parameters. Thus, within the sedimentary cover it was outlined zones of decreased density that correspond to regional trends of reservoir behavior. In the top of Mid-Albian sedimentary package the dilation areas are controlled by deep fault zones striking along the northern flank of the Western Black Sea sub-basin. In the Coniacian-Turonian and

Santonian sedimentary rocks it is delineated weak contrast zones of decreased density that are stretched from west to east along tectonic faults and bounded by lines of wedging out and erosion of their beds. The top of Upper Cretaceous carbonates and chalks is characterized by significant heterogeneity of density properties. Four dilation zones with anomalously low values are traced in near-latitudinal direction. To of them are attributed to Schmidt and Golitsyno gas fields where commercial flow rates of gas and condensate have been obtained in Schmidt-6 well. A similar tendency is found for Lower Paleocene sedimentary rocks where four sub-latitudinal dilation zones are traced. Plus, one can recognize some dilation patterns transversal to the terrain and certain lower density zones along internal shelf hinge, continental slope and toe that require further research and deserves exploration in near future.

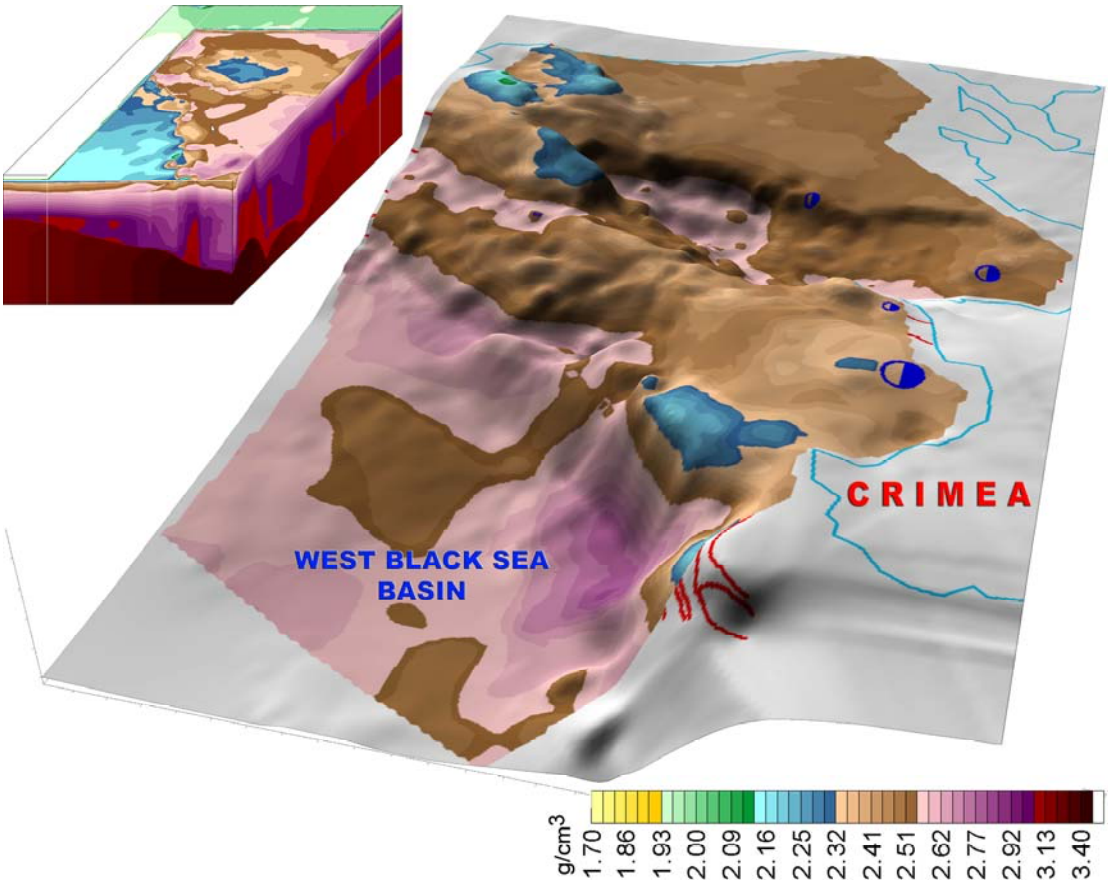

Figure 5 *3D geo-density model (top left) and its slice upon the top of the pre-Cretaceous acoustic basement (center). Dilation zones (higher reservoir potential) are shown in blue within the shelf and brown upon lilac background within the continental slope and toe.*

To analyze adequacy of horizon by horizon reservoir distribution prediction it was conducted comparison of that prediction with well test results. The analysis has confirmed the relevance of the prediction made with success ratio of 78%.

References

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